J. ENVIRONMENTAL SYSTEMS, Vol. 25(3) 287-302, 1996-97

ENVIRONMENTAL CONSEQUENCES OF POOR RUNOFF MANAGEMENT IN S.E. NIGERIA*

CHUKWUNONYE O. OWUAMA
Federal University of Technology, Owerri, Nigeria

ABSTRACT

Southeastern Nigeria lies within the humid tropical subregion. The geological, hydrological, and geomorphological conditions encourage gully erosion development when the soil is mismanaged. The growth rate of gully erosion in the subregion as recently observed from representative states is very alarming. Many roads, farmlands, streams/rivers, and utility buildings have been devastated. The main causes of this scale of gully erosion are poor runoff management and poor construction/maintenance culture. The escalative nature of the erosion can be controlled by legislation and effective monitoring of compliance.

INTRODUCTION

Southeastern Nigeria is a tropical subregion located within latitudes 4°N, 8°N and longitudes 6°E, 9°E. It is bounded on the west by the River Niger, east by the Cameroun highlands, far north by the River Benue, and south by the Atlantic Ocean (Figure 1). This area covers the states of Abia, Anambra, Akwa-Ibom, Cross River, Enugu, Imo, and Rivers. The area lies within the tropical rainforest and sahel Savanna belts, with abundant rainfall, varying landforms, thick natural vegetation, and abundant mineral resources. The thick natural vegetation has been depleted as a result of population growth, persistent farming, and rapid socioeconomic development, including mineral exploitation. The area is

*I express my gratitude to the UNDP 4th country program under which patronage this research was undertaken.

doi: 10.2190/RLXF-FNQN-JF2G-GVVP
http://baywood.com

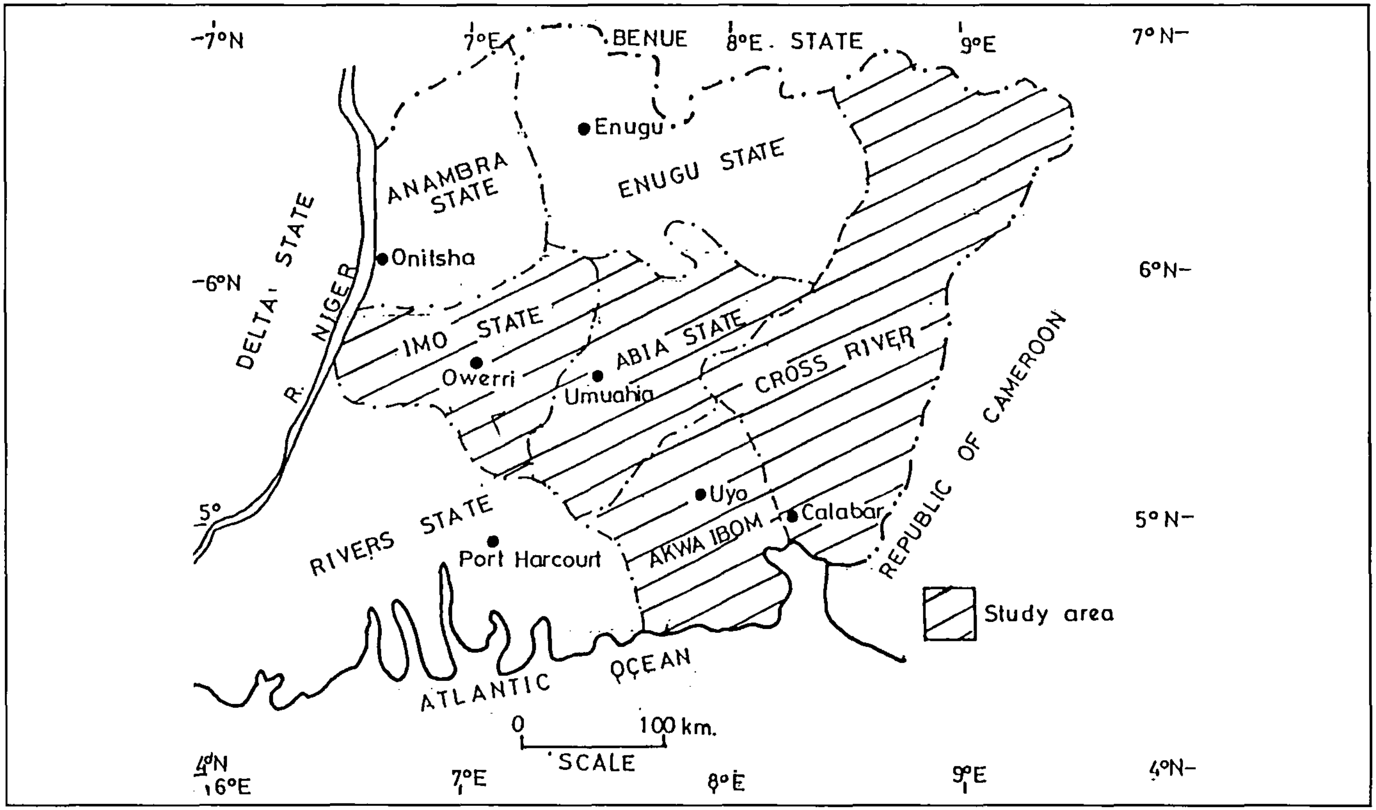


Figure 1. Map of S.E. Nigeria showing the study area.

therefore experiencing high levels of natural and manmade environmental hazards. These include soil erosion, landslides, flooding, and oil pollution.

Studies have been conducted by a number of groups to assess the environmental problems. Published reports concern the causes of the erosion [1-7] and possible control measures [8-10]. The study reported in this article provides an extensive evaluation of problems of gully development in the area and examines how poor runoff management, in particular, has undermined the integrity of the environment.

ENVIRONMENTAL SETTING

The study area was restricted, concentrating on Abia, Akwa-Ibom, Cross River, and Imo States, in a way that represents a cross section cutting across the geographical, hydrological, and geological boundaries typical of the subregion.

Geography

The area under investigation is bounded in the north by the states of Anambra, Benue, and Enugu; in the south by the state of Rivers and the Gulf of Guinea; in the east by the Cameroun highlands; and in the west by the River Niger (Figure 1). It covers an area of 43,977 km^2 with a population of 9,631,833 (1990 estimate). The average population density is 219 persons/km^2, with individual states as follows: Abia, 421/km^2; Akwa-Ibom, 331/km^2; Cross River, 65/km^2; Imo, 462/km^2.

A rainfall pattern of double maxima occurring mainly in the months of July and September, with an annual average varying from 2500 mm in the coast to 2000 mm in the hinterland, is typical of the area [11, 12].

The landform varies from undulating plains in the west and southwest to Cuestas and intermontane ravines in the eastern half. The major drainage forms include the following rivers: Niger, Cross, Imo, Urashi, Calabar, Qua Iboe, Njaba, Aba, Blue, and Aso, and over thirty streams all emptying their waters southward directly or indirectly to the Atlantic Ocean.

Geology

The geology of the area comprises [13]:

- Alluvium and coastal plain sand (Benin formation), deposited during the Neogene period. This is the predominant geologic formation found in the western part of the area of study.
- Bende-Ameki formation (Nanka sand) of the Eocene age.
- Imo shales, upper coal measures (Nsukka formation), false bedded sandstone (Ajali sandstone), and lower coal measures (Mamu formation). These were deposited in the Lower Pleocene.

- Nkporo shale (Campanian age) and Odukpani formation (Cenomanian age). These belong to the Upper Cretaceous while the Asu River group were deposited in the Lower Cretaceous.
- The Basement complex, which is restricted to the eastern part, dates back to the Precambrian.

Soil Type

Under the humid tropical climate characteristic of the area, deep in-situ weathering takes place on the geologic materials. The composition and characteristics of the weathered rock (soil) depends very much on the parent rocks from which it was formed. Common soil types in the area are [13, 14]:

- deep porous red to brown soils of the coastal plain sand, locally referred to as red earth or acid sand;
- red clayey and gravelly brown soils derived from acid crystalline rocks;
- the lithosols which are the shallow stony soils occurring on the steep slopes over resistant rocks and sandy/silty shales;
- the hydromorphic soils which are pale colored and mottled, and usually influenced by seasonal water-logging caused by the underlying impervious shales.

DATA COLLECTION

The study sought to determine the magnitude of gully erosion, the extent of damage to the environment, the macro-factors responsible for the rapid growth of gullies witnessed in the area, and the most effective techniques of checking the spread of gully erosion.

The survey was conducted according to the following format:

1. Administration of Questionnaires:
   Questionnaires were sent to all persons, private firms, and government departments charged with responsibilities of erosion control. The basic issues raised in the questionnaires concerned the
   - magnitudes of gullies known to the respondent;
   - any known causes of each of the gully erosion sites;
   - established programs for erosion prevention and the effectiveness of such programs;
   - erosion control projects executed satisfactorily and non-satisfactorily;
   - causes of failure and delay in erosion control works; and
   - modes of execution of erosion control projects at each stage of study/design, construction, and supervision (i.e., whether by direct labor or by contract).

2. Collection and Collation of Reports:
   Reports on soil erosion prepared by various organizations and agencies in the states and local government areas were collected and collated. The reports covered the lists of all known erosion sites, comprehensive studies of some erosion sites, preliminary designs of some erosion control works, ethical issues raised by erosion control measures, and climatic data.
3. Field Investigations:
   Based on the available records, gully erosion sites were randomly selected for investigation (while ensuring that every local government area in the states was covered). The erosion sites were physically evaluated in terms of:
   - length, width, and depth of gully;
   - the immediate causes of the gully development;
   - the remote causes of the gully development;
   - effects in the immediate and downstream vicinities;
   - geological disposition;
   - soil characteristics;
   - land use pattern vis-a-vis urban/regional plan; and
   - the most effective control methods that can be adopted.

   Aerial photographs and satellite imagery were recognized as valuable tools in this study but inaccessibility of such recent records restricted the study to direct observations.
4. Desk Work:
   The information gathered in 1, 2, and 3 above was articulated and statistically evaluated. References were made to the experiences of various erosion research institutes, and proceedings of workshops on erosion in S.E. Nigeria.
5. Summary of Data:
   A total of 1195 active gully erosion sites were identified (as of October 1995), of which 314 were investigated. The distribution and scale of gully erosion sites according to states are shown in Table 1. At least 1.61×10^7 m^2 of the surface landmass representing 0.037 percent of the area of study, is presently gullied, and 3.09×10^8 m^3 of earth are projected to have been lost from these gullies, the average depth of which is 19.2 m.

Climatic data from seven meteorological stations for ten years (1985-1994) were analyzed. The average monthly rainfall patterns for typical stations (Calabar, Umudike, Orlu) are shown in Figures 2a, 2b, and 2c. An annual average of approximately 2500 mm on the coast to 2100 mm in the interior was observed. Rainfall intensities (mn/day) are relatively high in the main rainy months of June to September. The mean annual temperature varies between 22°C and 33°C and the relative humidity is in the range of 75 percent and 99 percent.

Table 1. Distribution and Scale of Gully Erosion Sites in Some States of S.E. Nigeria

State	Land Area $\times 10^6$ m^2	Active Gully Erosion Sites	Surface Area Affected $\times 10^6$ m^2	Landmass Removed $\times 10^7$ m^3	Proportion of Area Affected (%)
Abia	7,710	332	4.47	8.59	0.058
Akwa-Ibom	7,130	331	4.46	8.56	0.062
Cross River	23,753	227	3.06	5.87	0.013
Imo	5,384	305	4.11	7.89	0.076
Total	43,977	1,195	16.10	30.9	0.037

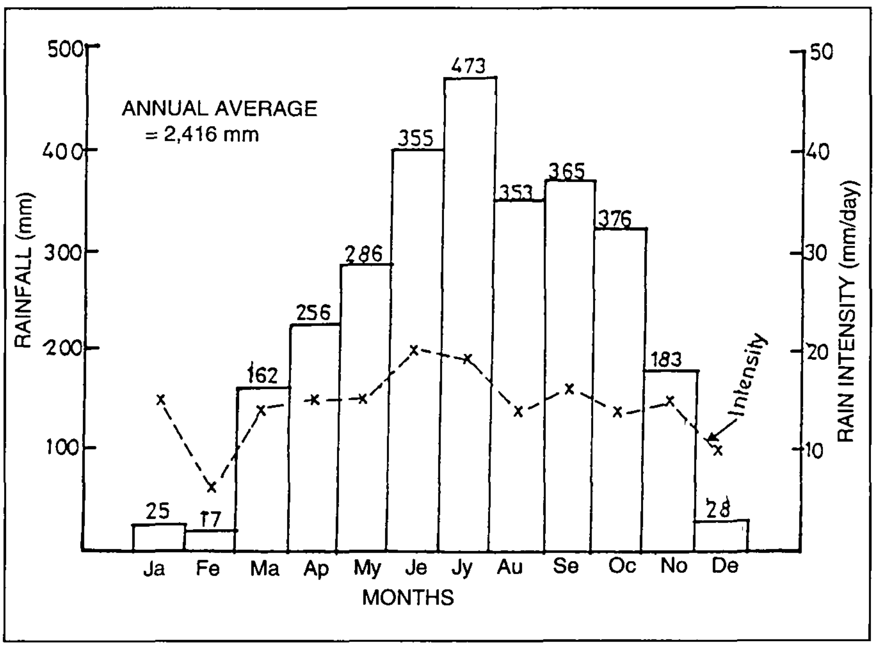


Figure 2a. Monthly average rainfall/rainfall intensity distribution for Calabar.

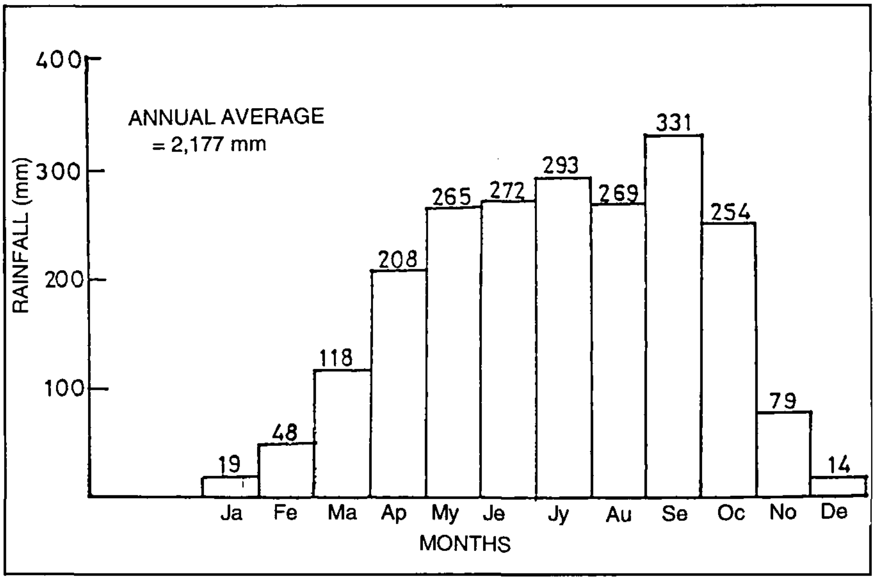


Figure 2b. Mean monthly rainfall (mm) for Umudike.

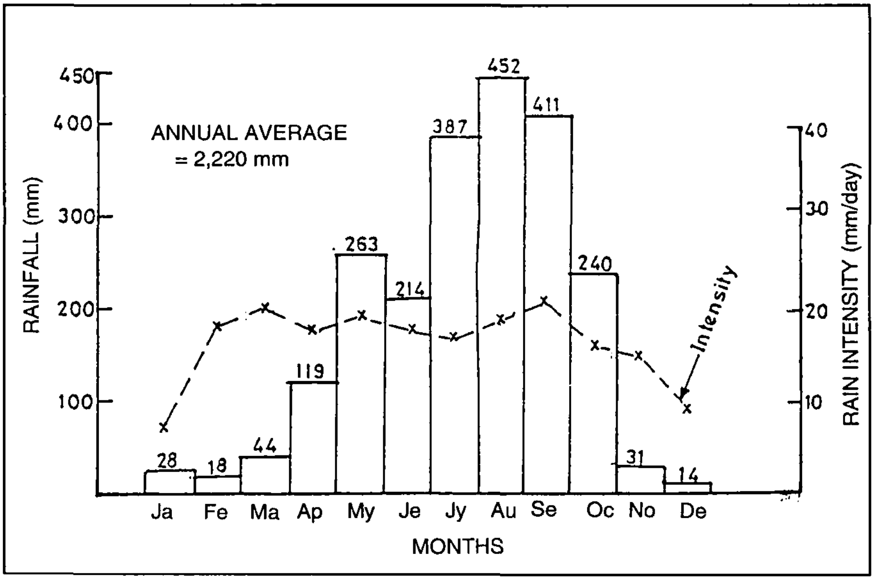


Figure 2c. Monthly average rainfall/rainfall intensity distribution for Orlu.

Soil samples were collected from eighty erosion sites across the area. The results of both the visual and laboratory analyses show that the soils at the erosion sites, irrespective of the nature of the parent rocks, belong to a class of poorly- to well-sorted sand of medium plasticity, inorganic clay, following the unified classification system. The grain size distribution envelope of the soils is shown in Figure 3. The soils have high to medium erodibility potential and are therefore susceptible to erosion on exposure [14].

The major causes of the accelerated gully erosion noticed in the area were identified to be macrofactors due to poor runoff management and poor workmanship. These factors include surficial runoff, developed areas runoff, concentrated runoff, poor road maintenance, wrong termination of culverts and drains, poor construction work, and fluvial processes.

The environmental system components most affected by gullies both in the immediate and downstream vicinities are roads, farmlands, streams/rivers, and utility buildings.

CAUSES OF THE ACCELERATED EROSION

Naturally, the environmental setting of the area under study would encourage soil erosion if the land is mismanaged. But the gravity of gully erosion observed is due mainly to certain macrofactors. The frequency and probability of occurrence of each factor are presented in Table 2 and illustrated in Figure 4.

Concentrated Runoff

This is an overland flow that is sourced from various discharge systems such as roads, foot paths, other open spaces, and bushes. The runoff concentrates both in volume and traction as it flows downslope toward gentle to steep slopes characteristic of dry and stream valley flanks. The terminal volume has a large depth component. The turbulent attitude of the flow and its undermining characteristics at discharge points initiate scouring, and generate cyclic landslides commonly observed in most of the gullies. It is a major cause of gully development in the region accounting for about 28 percent of the observed cases (Table 2, Figure 4).

Absence of diversion banks and channels on roadways and footpaths to divert the flow to absorption fields were mainly responsible for the flow concentration.

Surficial Runoff

This is an overland flow that originates from the immediate vicinity of the erosion site and ideally has the characteristics of laminar flow. The depth of flow is shallow when compared to its spread. It progressively undermines an erosional surface such as road pavements, culverts, or concrete drains. It is also a precursor to sheet and rill erosion and contributes extensively in the widening of gullies.

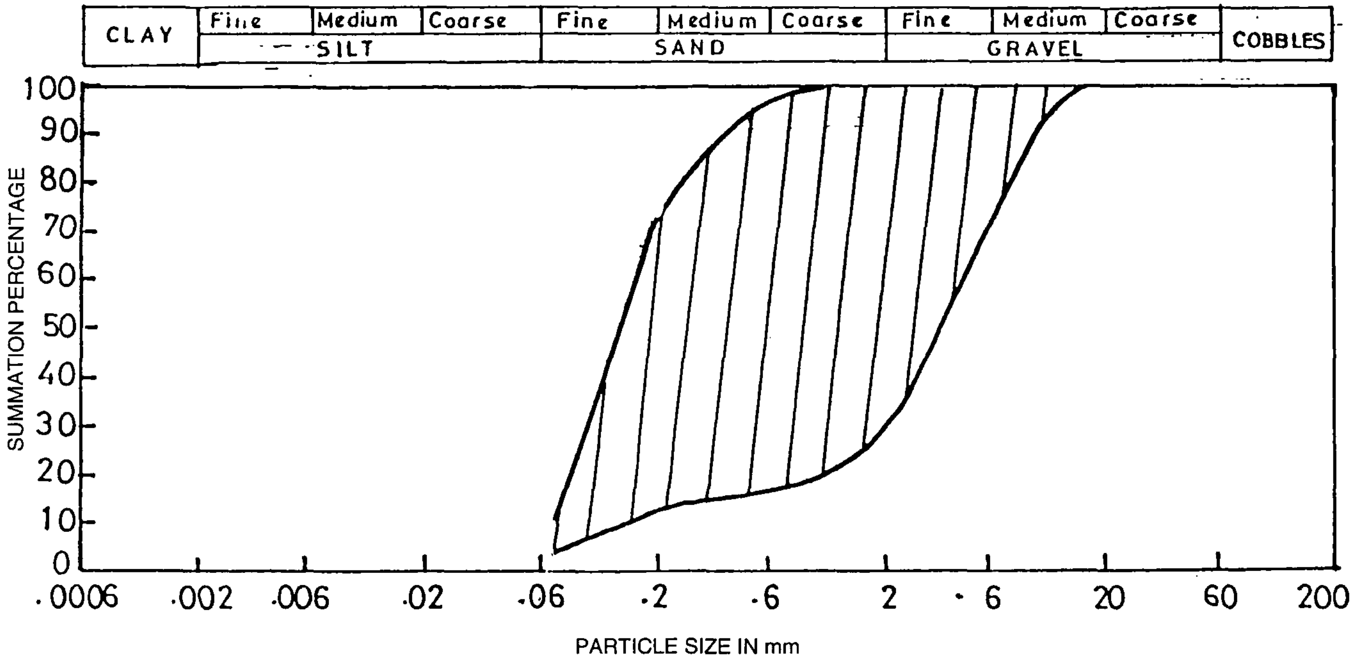


Figure 3. Grain size envelope of soils from typical gully erosion sites in S.E. Nigeria.

Table 2. Macrofactors Responsible for Accelerated Gully Erosion in S.E. Nigeria

Macrofactor	Frequency of Occurrence	Percentage Rating (%)	Probability of Occurrence
Concentrated runoff (cc)	278	28	0.86
Poor road maintenance (PRM)	181	20	0.58
Developed area runoff (DAB)	172	18	0.55
Surficial runoff (SR)	159	16	0.51
Wrong termination of culvert/ drain (WTC)	93	10	0.30
Faulty construction work (FCW)	64	7	0.20
Fluvial processes (FP)	10	1	0.03

Surficial runoff accounts for about 16 percent of gully cases observed in the region.

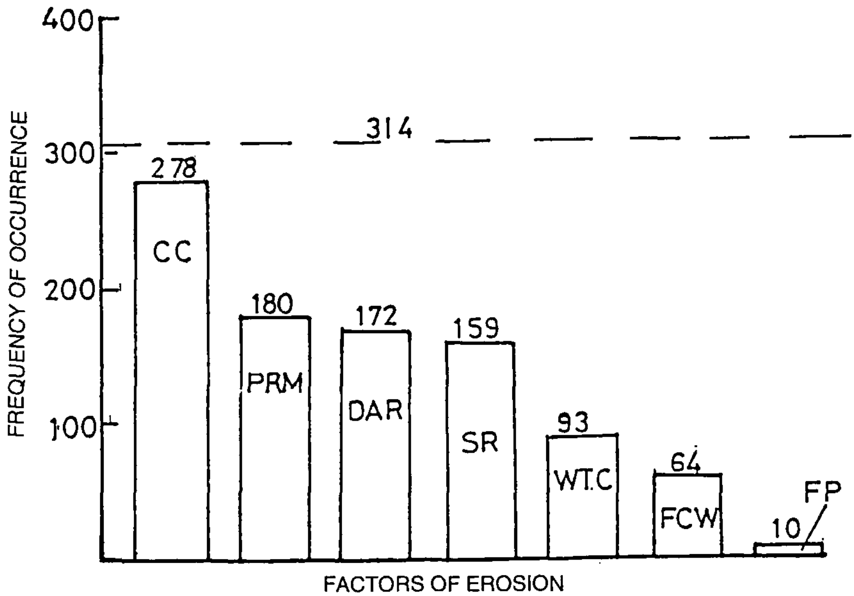
Developed Area Runoff

Most often public and private utility premises are either paved with concrete/ asphalt or left bare. The runoff sourced from these places including the building roof drops are referred to as developed area runoff. This discharge feeds concentrated and surficial runoffs, and initiates rills and gullies close to public and private premises. It accounts for about 18 percent of gully cases in the area. Absence of drainage facilities and vegetal cover in the premises encouraged the generation of the runoff.

Poor Road Maintenance

Poor road maintenance was identified to have caused 20 percent of gully cases. Most of the roads lacked side drains but wherever they do exist they were not maintained. Potholes were common features and runoffs criss-cross the roads without check.

Earthroads were often scraped and graded as a maintenance method but this lowers the road level below the surrounding ground level. This arrangement encouraged the concentration of flow along the road without an opportunity of diversion into an absorption field. At steep slopes the flow easily initiated gullies which rapidly grew in size to destroy the roads and neighboring farmlands and utility buildings.



LEGEND
CC = *Concentrated runoff*
PRM = Poor road maintenance
DAR = Developed area runoff
SR = Surficial runoff
WTC = *Wrong termination of culvert/drain*
FCW = Faulty construction work
FP = Fluvial processes

Figure 4. Frequency of occurrence of macrofactors of erosion in S.E. Nigeria.

Culverts and Drains

There were cases where road culverts and/or concrete drainage trenches were either poorly designed, poorly constructed, or wrongly terminated. The concentrated and surficial runoffs capitalized on this flaw to initiate the gully and then undermined the concrete structure which subsequently broke up. The failure continues with further deepening and widening of the gully. About 10 percent of the observed gully erosion sites were caused by this factor.

Faulty Construction Work

Cases were identified when engineered structures such as roads, bridges, drainage systems, and hydraulic structures failed functionally and/or structurally. This was either as a result of poor engineering work or uncompleted project execution. It created an enabling environment for the degradation of the soil around it thereby initiating an erosional process. It was observed that 7 percent of the erosion gullies were due to faulty construction work.

Fluvial Process

This refers to erosional activities that take place at riverbanks or coastlines as a result of the dynamics of rivers or ocean waters. This, combined with human activities, resulted in riverbank erosion or coastal erosion. This category constitutes about 1 percent of the observed gully cases in the area.

EFFECTS ON THE ENVIRONMENT

Gully development is commonly associated with slope failure which enhances the growth of the gully sizes. The consequence of gully development is to eat up the landmass, rendering the area unsuitable for any form of landuse. It is found in this study that at least 3.09×10^8 m^3 of soil has been removed by gully erosion and deposited in the various environmental systems as pollutants. As noted, the environments so affected include roads, farmlands, streams/rivers, and public/private utility buildings. The frequency and probability of damage on the environmental systems components are shown in Table 3 and Figure 5.

Roads, whether of earth or asphalt, suffer from rill and/or gully erosion at the uphill and valley flanks while deposition of materials takes place at the valley floor. The deposits (silt and sand) easily hinder free flow of traffic. Roads constitute about 30 percent of the environmental system elements observed to suffer from degradation by gully processes.

Table 3. Environmental Systems Affected by Gully Erosion in S.E. Nigeria

Environmental System	Frequency of Occurrence	Percentage Rating (%)	Probability of Occurrence
Road	267	30	0.85
Farmland	232	27	0.74
Water system	191	23	0.61
Utility building	180	20	0.57

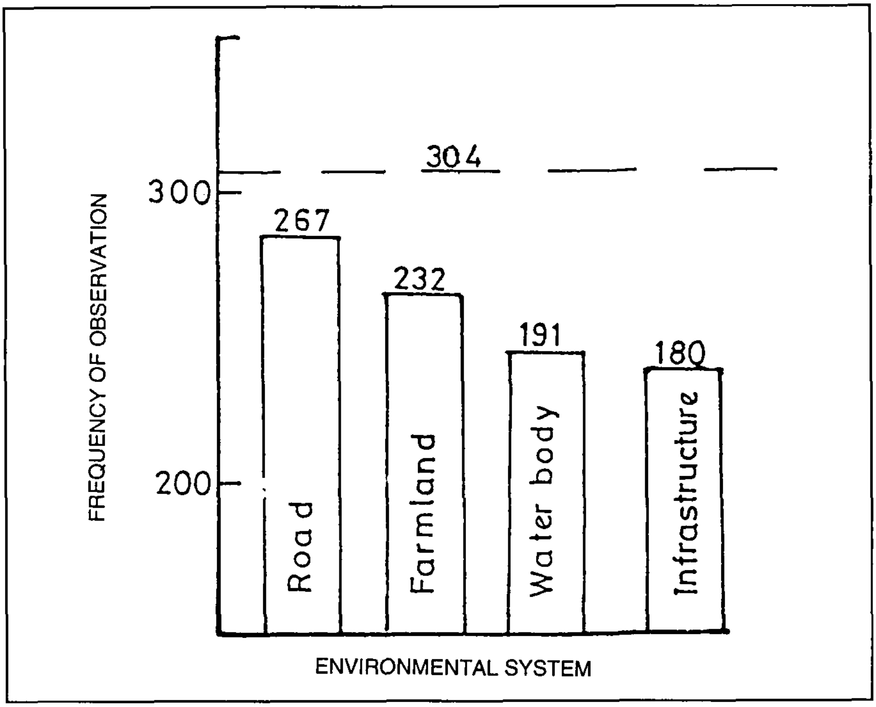


Figure 5. Frequency of observations of damages caused by soil erosion on various environmental systems in S.E. Nigeria.

Farmlands

Farmlands are either gullied by the concentrated runoff at the slopes or silted up at the lowlands. The situation renders the land unsuitable for farming practices. It was estimated that 27 percent of the observed cases of degradation affected farmlands (Table 3, Figure 5).

Streams/Rivers

In this system the most common phenomenon is siltation in which case materials eroded from the catchment area were deposited in the fluvial environment. Riverbank failures involving complex processes of shearing, dissolution of silts and clays, and undermining of the river water also occurred. Siltation generally resulted into drying up of some streams thereby affecting aquatic life. The muddy nature of the stream-waters makes the treatment for domestic water needs more expensive. Water depths became shallower as a result of siltation and this usually affects free flow of river crafts. About 23 percent of the observed cases affected streams and rivers.

Public/Private Utility Buildings

These include residential buildings, churches, schools, and commercial establishments. They were observed to have been affected by erosional activities and/or siltation of eroded materials. In some cases the infrastructures had been eaten up by gullies or overflooded with deposits. Some 20 percent of the observed cases of damage affected utility buildings.

CONCLUSION

Although the well-known factors of erosion are rainfall (erosivity), soil type (erodibility), topography (slope), and land management [15], it was observed in this study that rainfall characteristics in the subregion have not so significantly changed as to have caused the very severe erosional activities noticed. Soil types, whose properties depend on the parent rock and the environment of formation or deposition had remained relatively unchanged but for minor structural and mineralogical alterations due to deeper weathering processes following persistent copious rainfall over considerable, perhaps geologic, time periods. This possible but minor alteration could not have accounted for the magnitude of gully erosion recently noticed in the subregion. Slopes had remained relatively stable within the short period except for minor geological effects of denudation which progressively modifies topographic profiles. This cannot therefore account for the high incidence of gullies in the area. The fourth factor, land management patterns, had followed the trend of population pressure on land, and of literacy on environmental conservation practices.

There has been increased population, and as well rapid development in urban and rural settlements. These involved removal of vegetation cover and reshaping of landscapes to build roads, houses, markets, schools, hospitals, etc. Tremendous runoffs are generated from these sources. Poorly managed runoff indiscriminately scours landscapes along low hydrologic gradients initiating and activating rills and gullies as it flows downhill to natural drainage channels or depressions. Poor runoff management was found to be rampantly practiced in the area and this resulted in the high incidence of gully erosion. Poor engineering construction and maintenance cultures were complementary.

In order to control and contain further escalation of the gully erosion hazards, efforts can be directed toward the following measures:

- regular and appropriate maintenance of roads;
- provision of diversion banks and diversion channels, especially on earth roads;

- termination of culverts and drains close to local base level, where the flow will cause minimal damage to the soil;
- optimal grassing of open spaces;
- efficient drainage of private, public, and commercial premises;
- tarring of steep slopes on roads accompanied by concrete drains;
- creation and preservation of water absorption fields; and
- mass education on land conservation.

A detailed examination of the various control methods would be the subject of further research. Legislation and monitoring of the compliance can assure effective control of gully erosion in the subregion.

ACKNOWLEDGMENTS

I extend my appreciation to the contributions of the following participants: O. O. Ntima, Dr. N. K. Ndukwe, Dr. E. Ekop, and Effiong Fuller.

REFERENCES

1. W. J. Sluiter, *Some Geomorphological Factors and Their Influence on Erosion in the Osina Basin,* Proceedings of the International Symposium in S.E. Nigeria, Owerri, pp. 43-53, 1988.
2. J. Poesen, *Surface Seal Formation and Soil Erosion Subprocesses,* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, pp. 60-67, 1988.
3. D. F. Tee, *Groundwater, Surface Water and Erosion. How Related?* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, pp. 76-81, 1988.
4. H. O. Madukor, *Soil Physical and Chemical Properties Affecting Erodibility of Some Soils in S.E. Nigeria,* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, pp. 102-105, 1988.
5. O. I. Abarikwu, *The Challenges of Erosion in Imo State,* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, pp. 116-119, 1988.
6. S. C. Teme, *An Assessment of Coastal Erosion in Parts of Akwa Ibom State of Nigeria,* Proceedings of the 6th International Congress, IAEG, Amsterdam, pp. 2813-2818, 1990.
7. C. O. Owuama, *Genesis of River Bank Erosion in the Niger Delta System,* Proceedings of the 6th Congress, IAEG, Amsterdam, pp. 280-2811, 1990.
8. C. C. Asiabaka and Tb. M. Boers, *An Analysis of the Existing Traditional Methods of Farming and Erosion Control among Farmers in S.E. Nigeria,* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, 1988.
9. S. E. Etukudo, *Soil Erosion Control. A Case Study in Akwa Ibom State,* Proceedings of the International Symposium on Erosion in S.E. Nigeria, Owerri, pp. 130-141, 1988.
10. C. O. Owuama, *A Physical Model for Control of Sheet Erosion,* 6th International Congress, IAEG, Amsterdam 6-10 August, pp. 1689-1696, 1990.

11. NEDECO, *The Waters of the Niger Delta, Technical Report,* The Hague, 301 pp., 1960.
12. G. G. Publications, *Atlas of Imo State,* 155 pp., 1979.
13. S. A. Ola, *Tropical Soils of Nigeria in Engineering Practice,* A. A. Balkema, Rotterdam, 326 pp., 1978.
14. A. A. Wagner, *The Use of Unified Soil Classification System by the Bureau of Reclamation,* Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, London, Vol. 1, 125 pp., 1957.
15. M. De Boot and D. Gabriels, *Assessment of Erosion,* Proceedings of the Workshop on Assessment of Erosion in USA and Europe, State University Ghent, Belgium, 563 pp., 1978.

Direct reprint requests to:

Professor C. O. Owuama
Department of Civil Engineering
Federal University of Technology
P.M.B. 1526 Owerri
Imo State, Nigeria